Large Aperture HPD R&D status and future for HK

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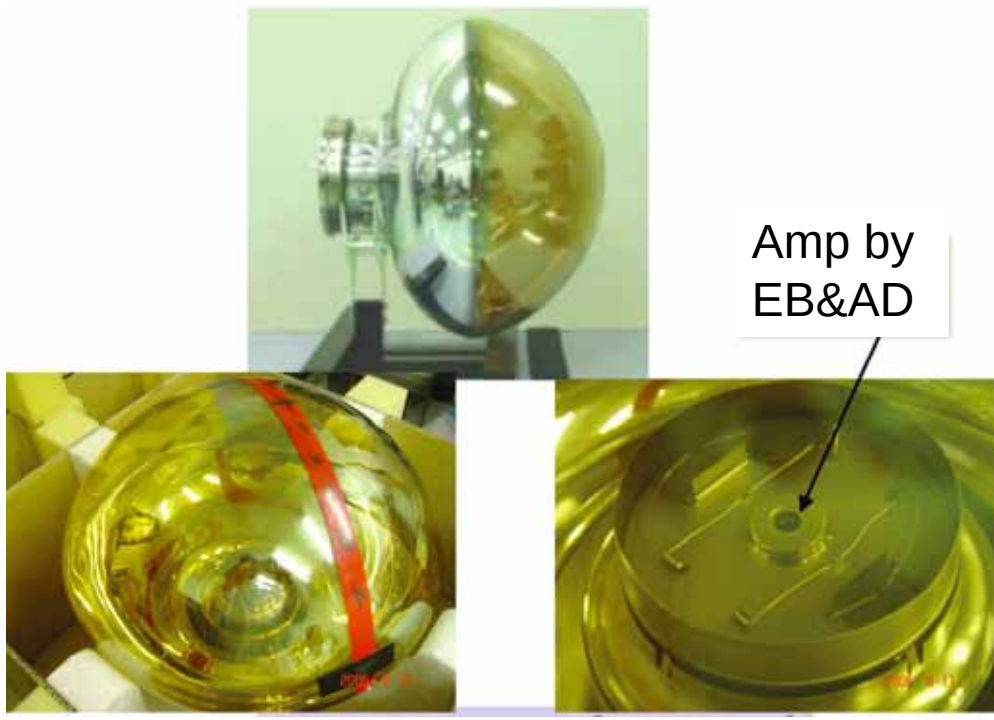
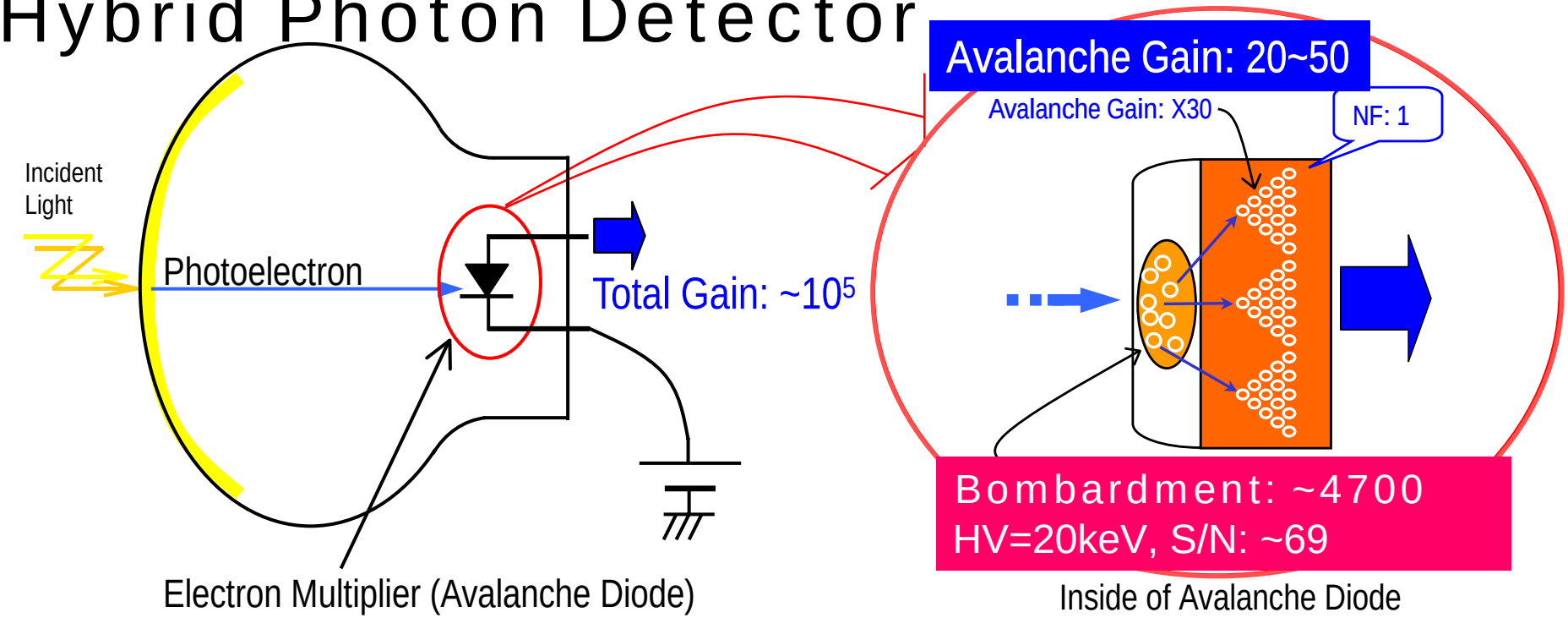
20inch PMT



13inch HPD

Hybrid Photon Detector



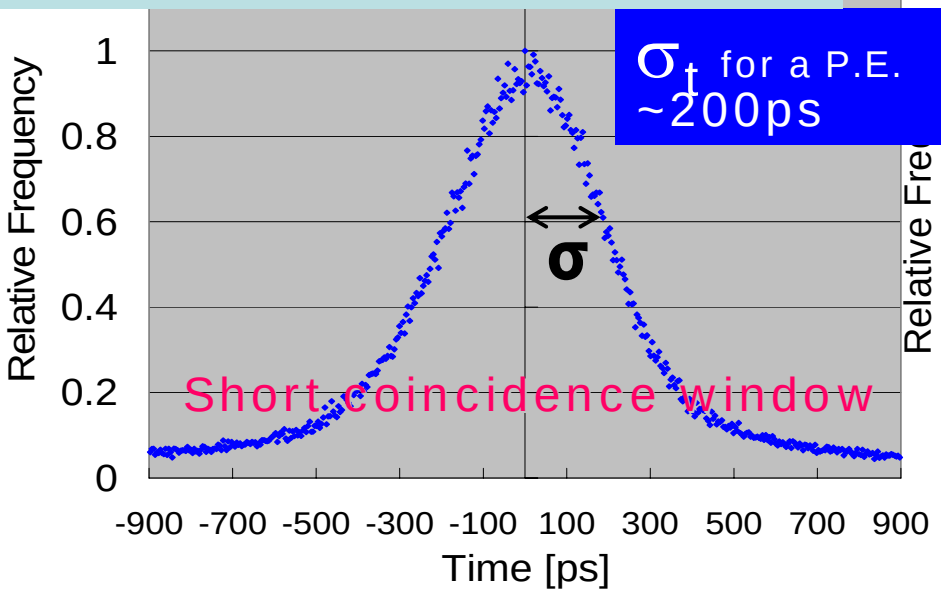
HPDs

- ✓have a simple structure. → lower cost than PMT and easy Quality control.
- ✓EB takes major role in e-amplification → small statistical fluctuation
  → Small Δpath of P.E. → Better timing resolution
  → Small Δgain of P.E. → Better S/N
- ✓but lower gain → a part of readout electronics implementation near HPD

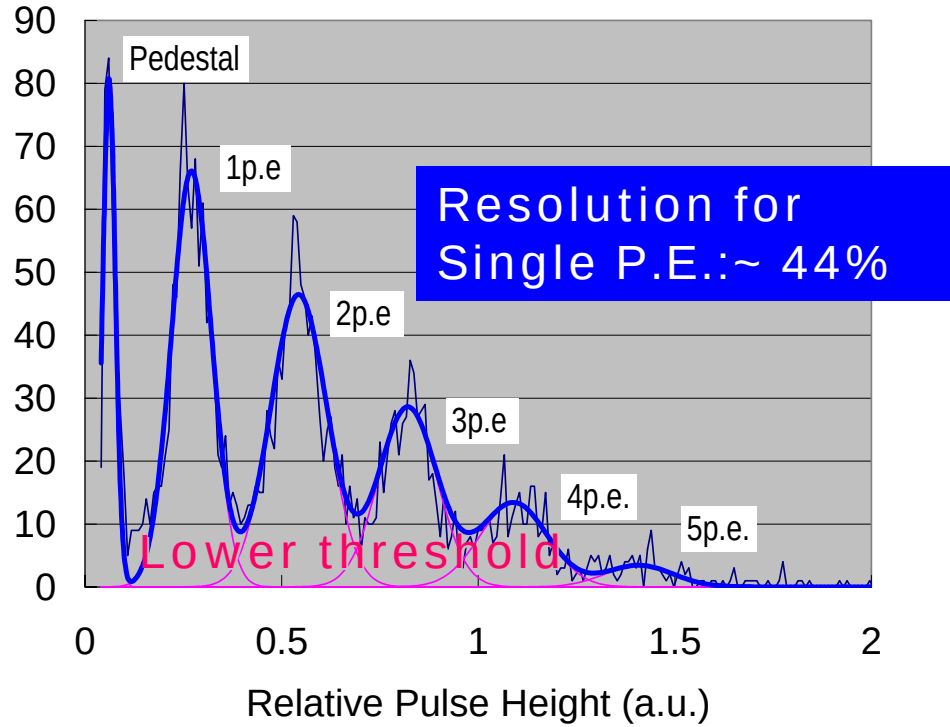
What is Our expected result?

13inch HPD performance and impact

Test condition:
HV=+20kV, Bias=370V
Light Source:Pulsed Laser (PW:~70ps, λ:~400nm)



σ_t for a P.E. ~200ps



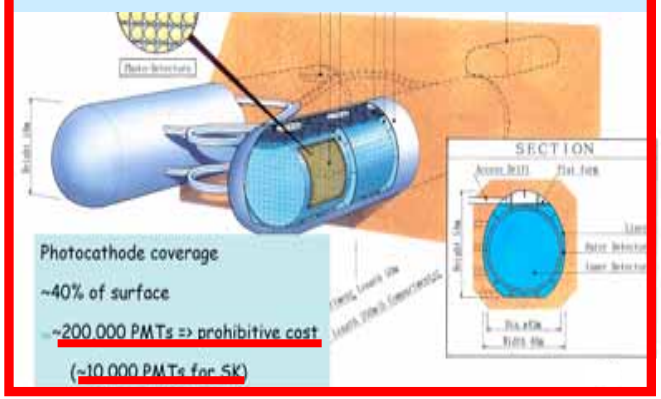
Resolution for Single P.E.:~ 44%

Suppression of BG for low E ν event

Better low E ν detection efficiency
Good ν energy resolution
etc

Solar neutrino, N-decay measurement

Hyper Kamiokande; the next generation water-Cherenkov detector



HPD system

HPDs

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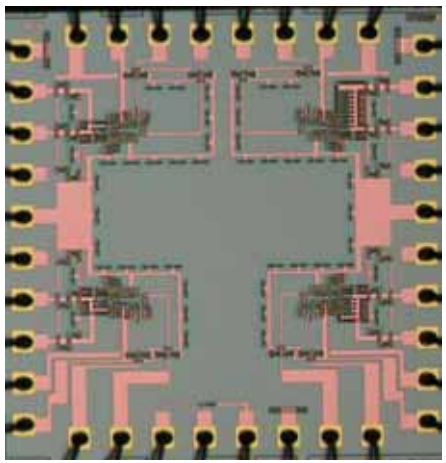
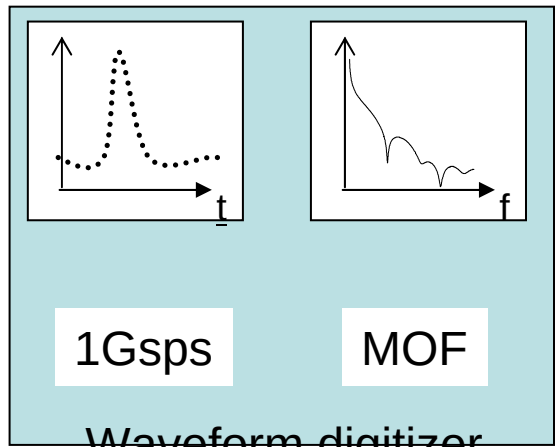
13-inch HAPD



Pre-amplifier(ASIC)



Flexible & tolerant system for
baseline instability
electric & magnetic interferences from external environment
(i.e. ripple of power supply, ground bounce, ground loop etc)

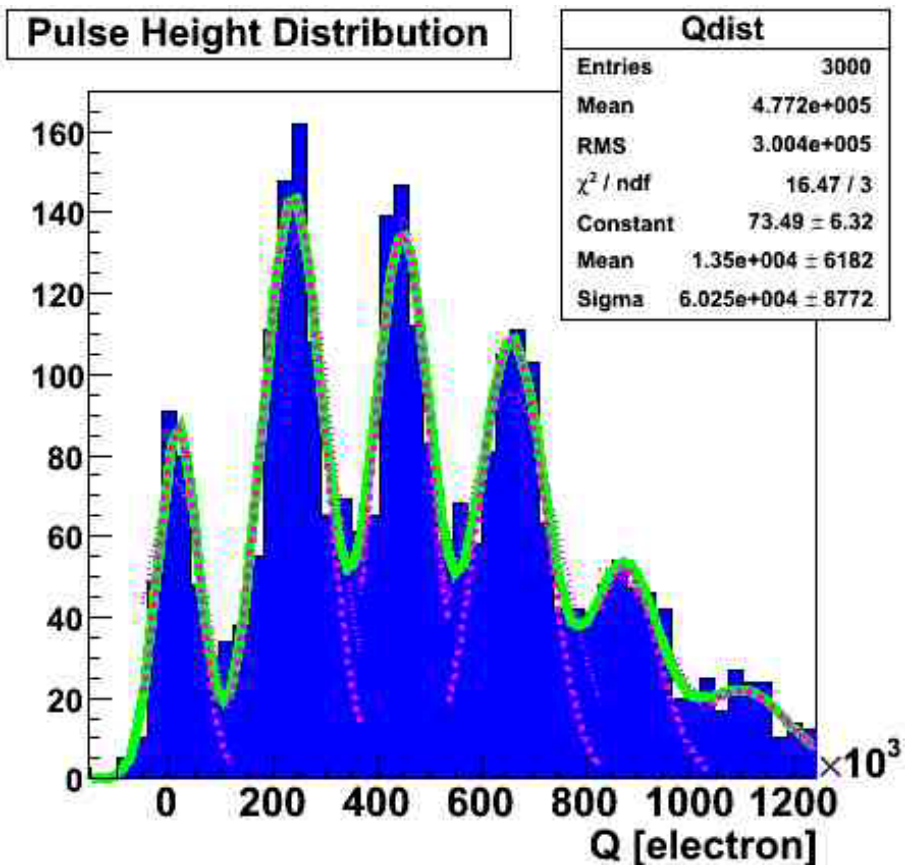
T&Q performances are evaluated using this system

HPD performance(detail)

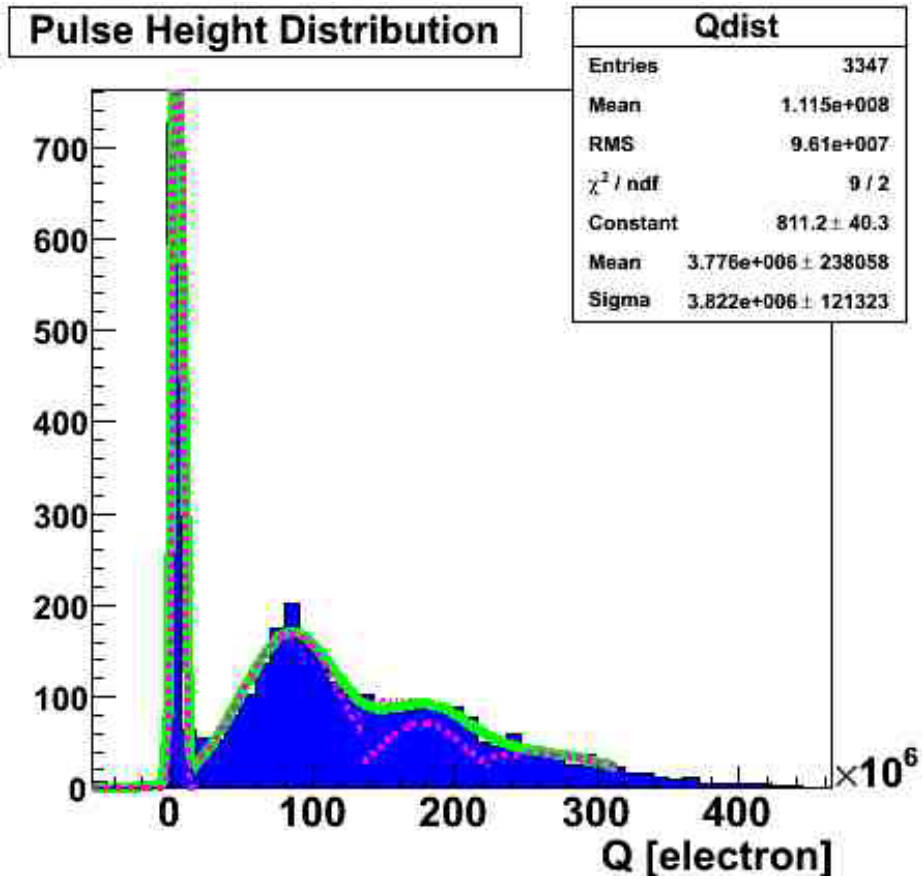
- Energy measurement related items
  - Comparison between HPD and PMT
  - Dynamic range
  - Position dependence of relative gain
- Timing measurement related items
  - Comparison & # of P.E. dependence
  - HV dependence
- Dark rate

Comparison of HPD and PMT

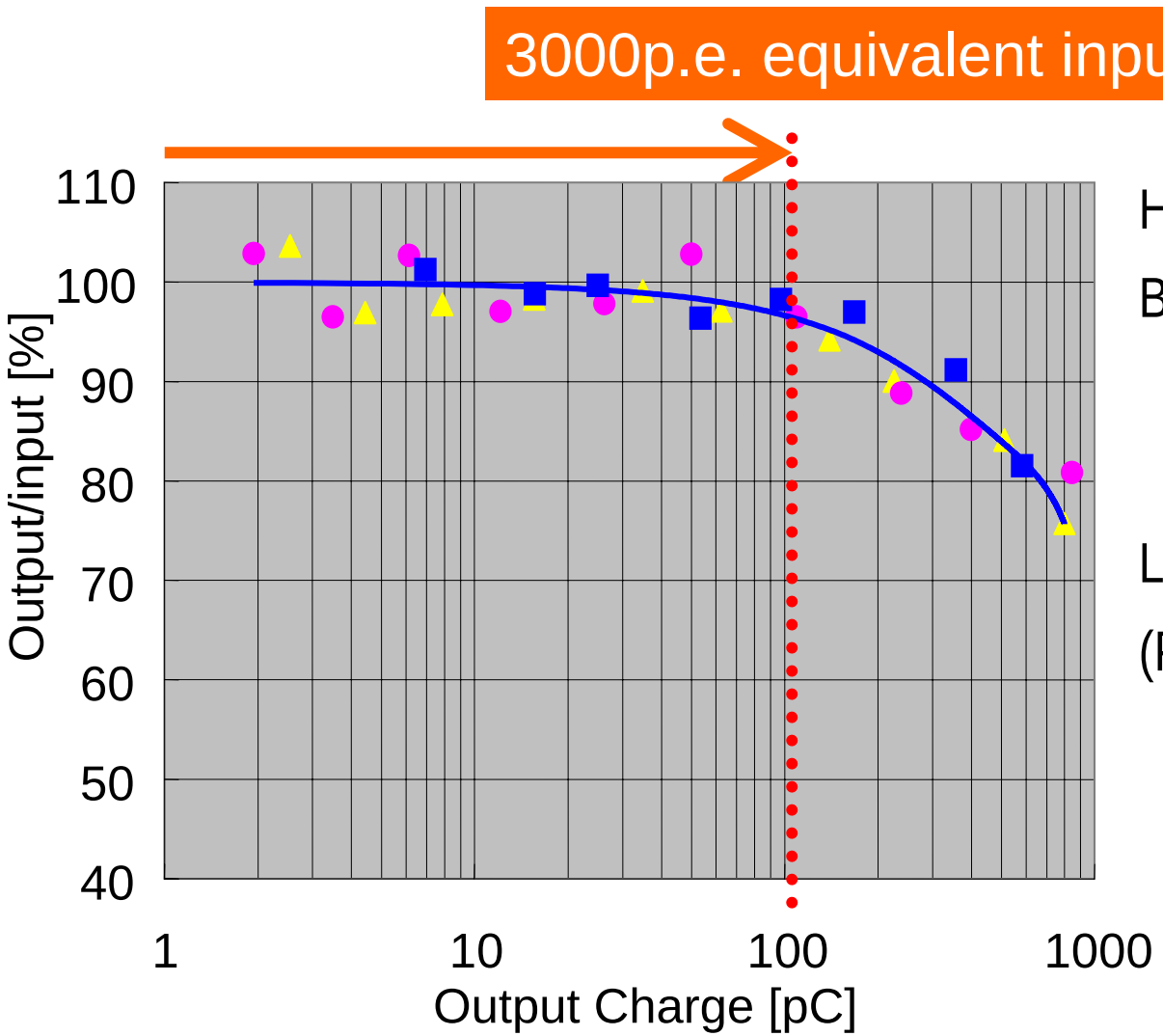
HPD (HV=12kV bias=330V)



PMT(13inch)



Dynamic Range (no preamplifier)



HV=+20kV,

Bias=290V for Sample A

370V for Sample B

390V for Sample C

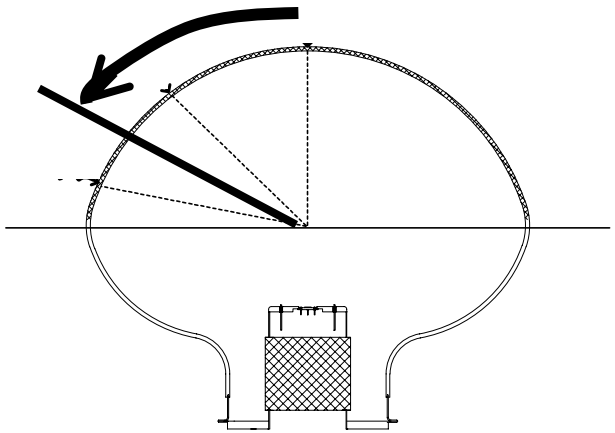
Light Source: Pulsed Laser

(PW: ~70ps, λ : ~400nm)

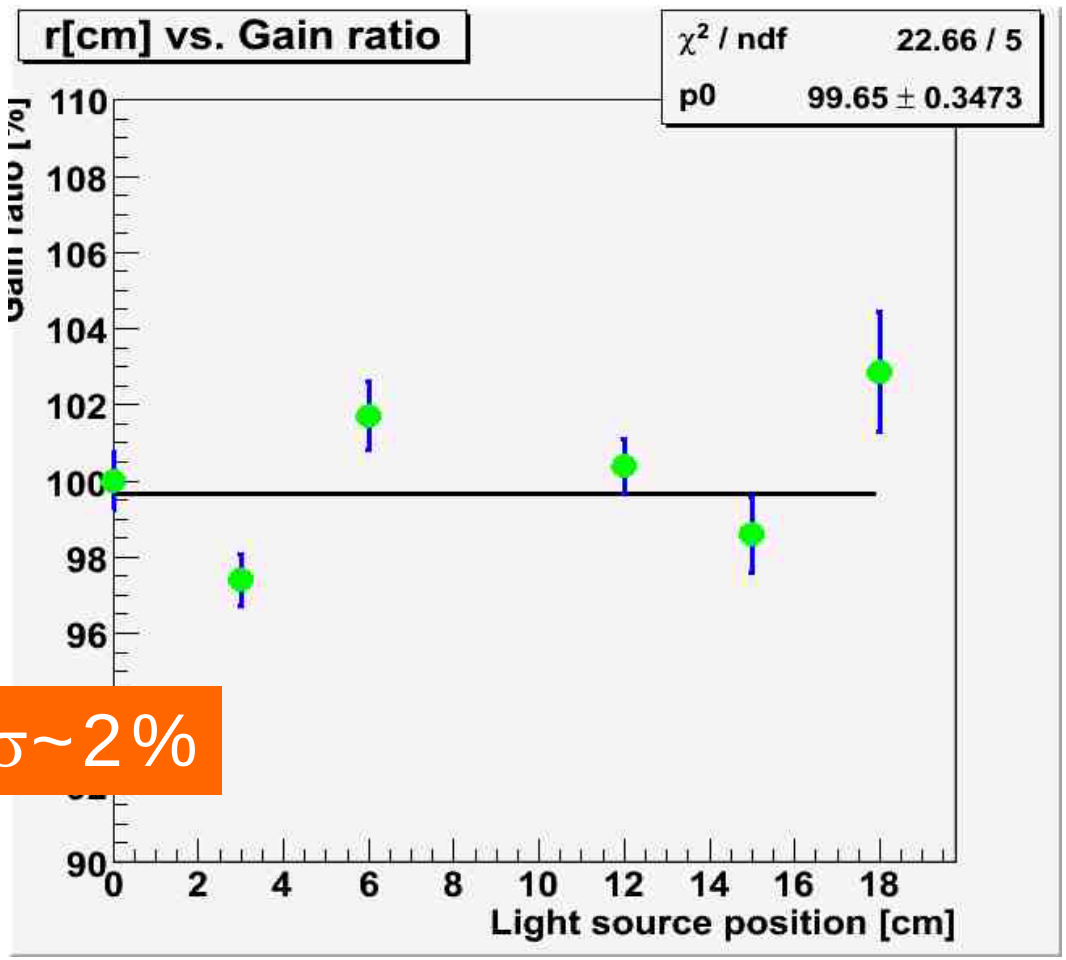
-3% Deviation at Output Charge of 100pC (~3000p.e. input signal intensity equivalent at total gain of ~2x10^5)

Position dependence of gain

18cm ~65deg.



for photons<5

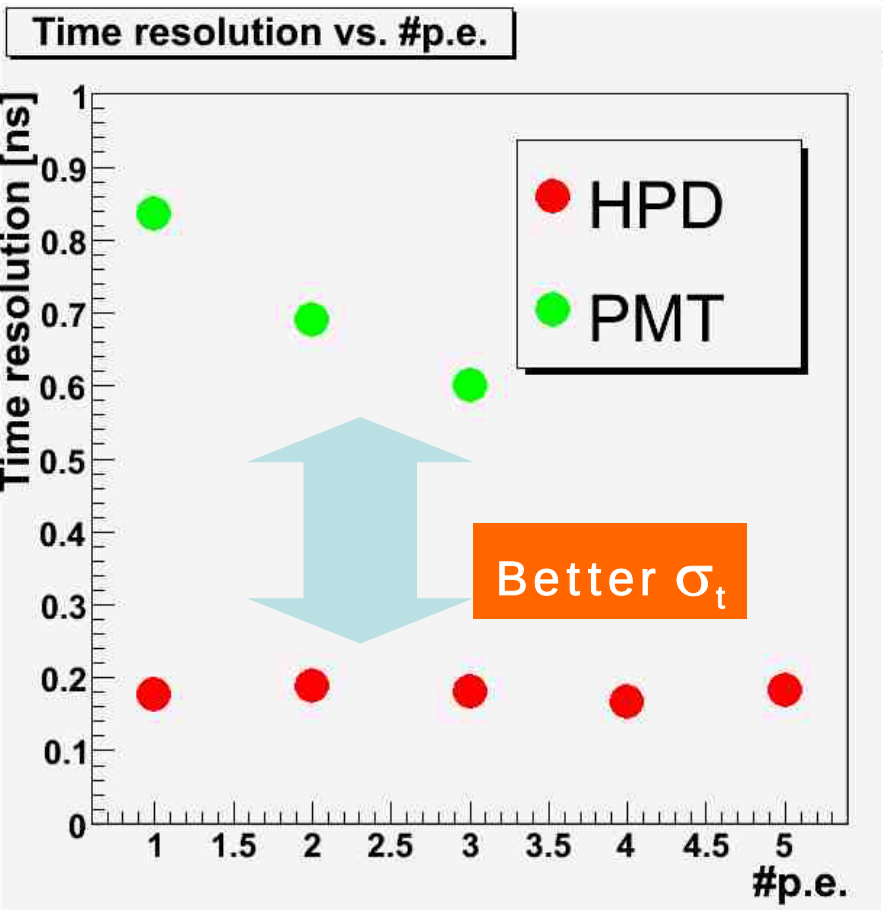


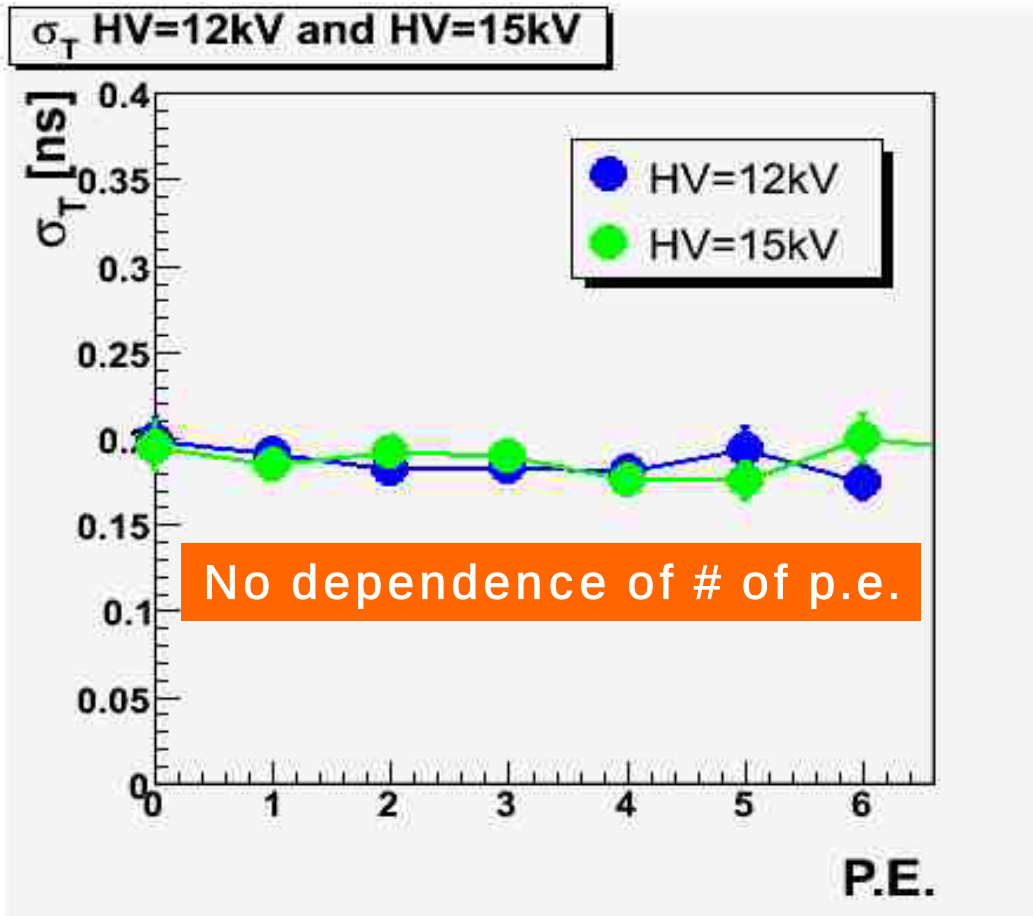
Gain uniformity:σ~2%

Timing resolution

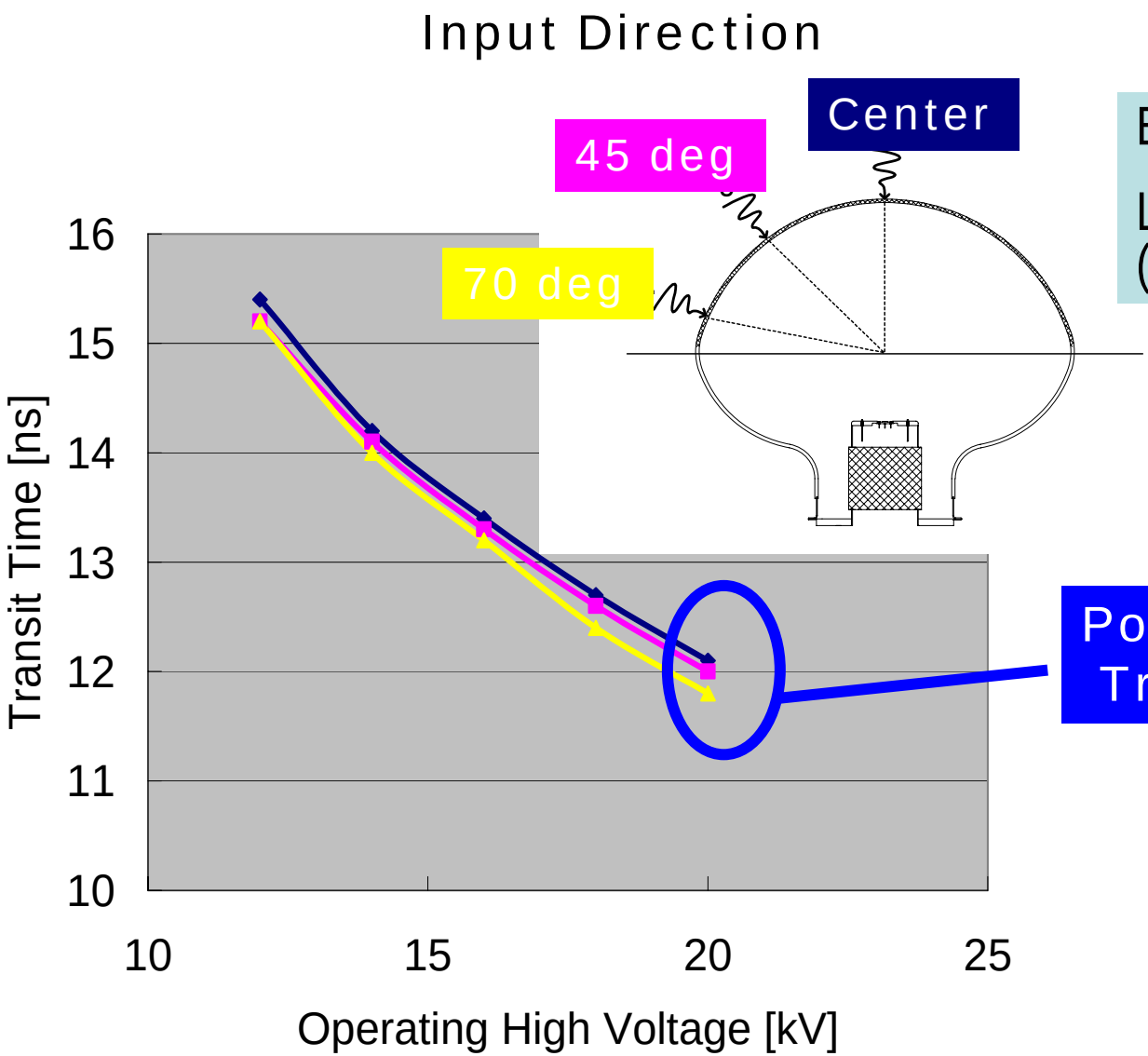
Laser illuminated

HV=12kV bias=330V





Photoelectron Transit Time

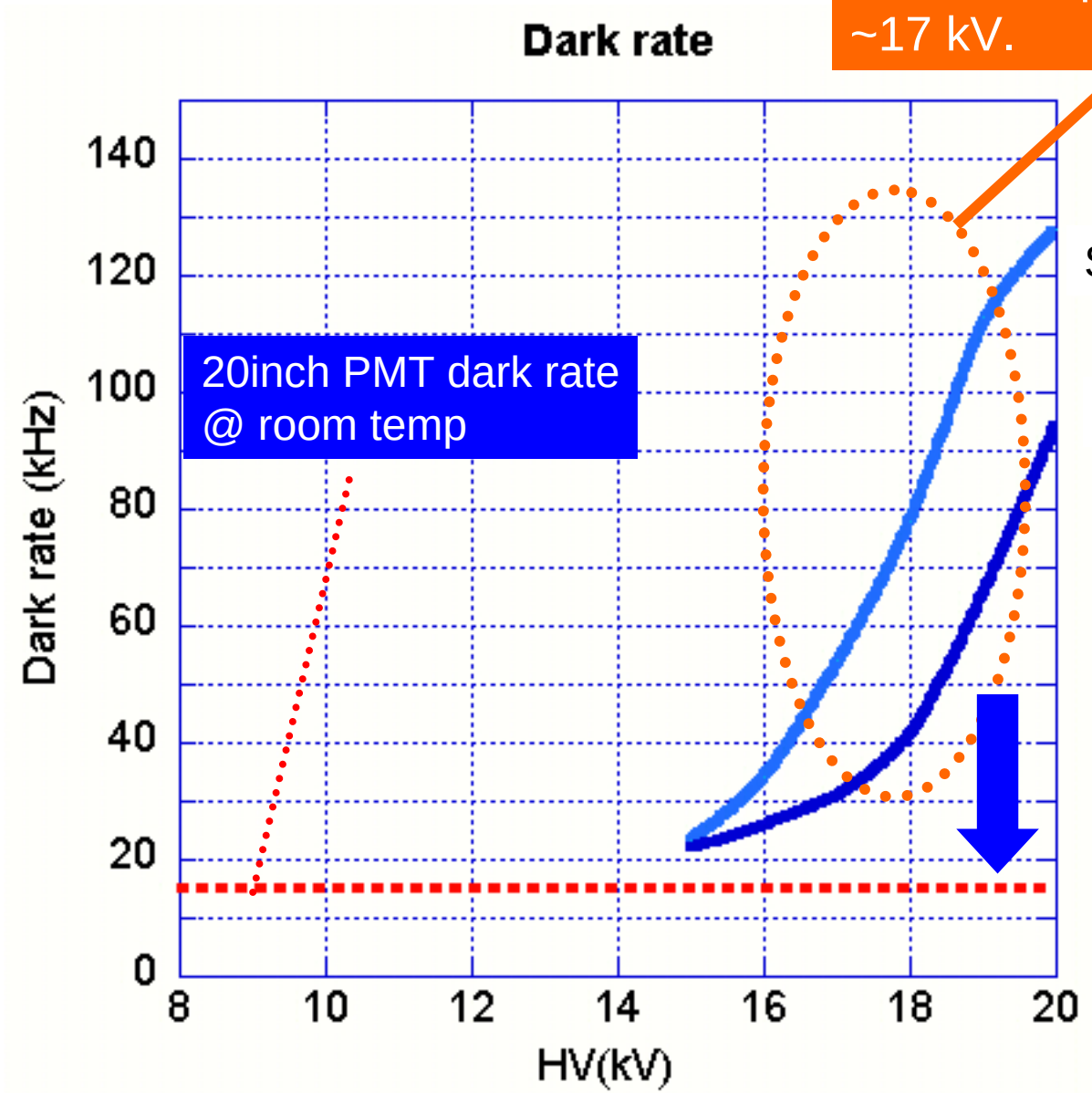


Bias=290V

Light Source: Pulsed Laser
(PW: ~70ps, λ: ~400nm)

Position dep of
Transit time < 1 nsec

Dark rate



Dark rate quickly goes down below ~17 kV.

20inch PMT dark rate @ room temp

Sample#1

Sample#2

After modification of HPD, Dark rate HPD@20kV~20inch PMT

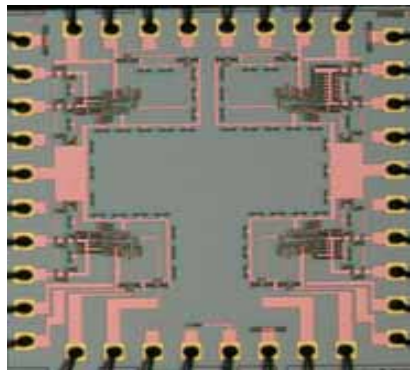
Dark count : 15kHz

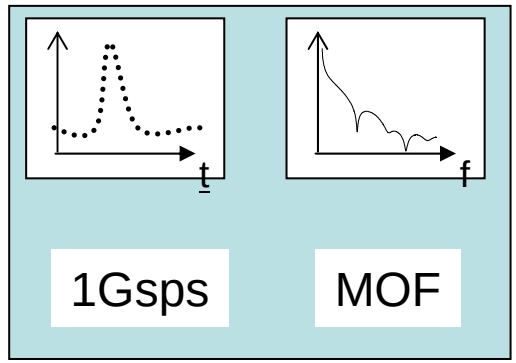
Comparison of Developed HPD and Conventional Large-Aperture PMTs

Parameters*		Developed HPD (13-inch HPD)	13-inch PMT (R8055)	20-inch PMT (R3600-02 for SK)
Order of Gain		10^5	10^7	10^7
Single Photon Time Resolution (σ)		190ps	1400ps	2300ps
Single Photon Energy Resolution		44% (preliminary)	70%	150%
Pulse Response	Rise Time	1ns	6ns	10ns
	Pulse Width	2.2ns	10ns	20ns
Transient Time		12ns	100ns	95ns
Dynamic Range (Signal Intensity in p.e.)		3000 p.e.	2000 p.e.	1000 p.e.

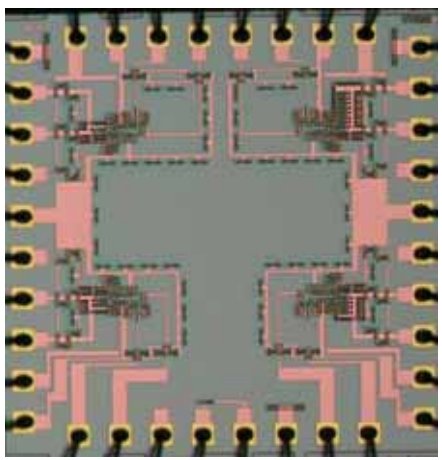
** Under rated operating voltage of 1.5kV for R8055 and 2kV for R3600-02. HV of +20kV bias voltage of 390V for HPD*

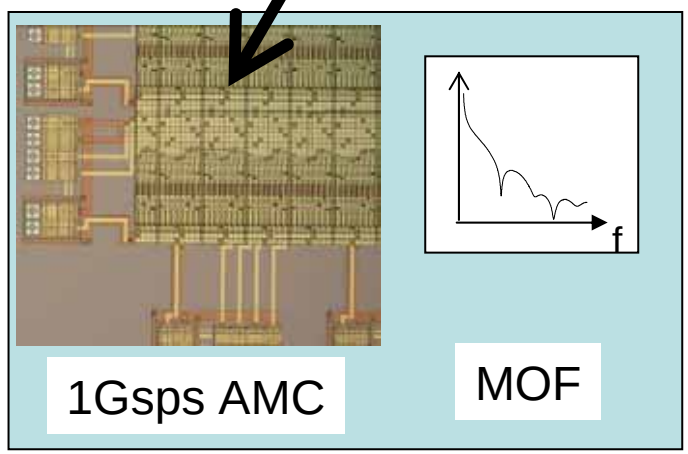
HPD electronics status





Under developing



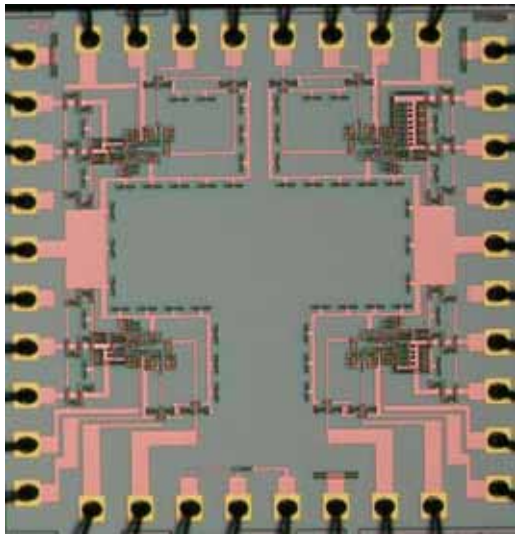


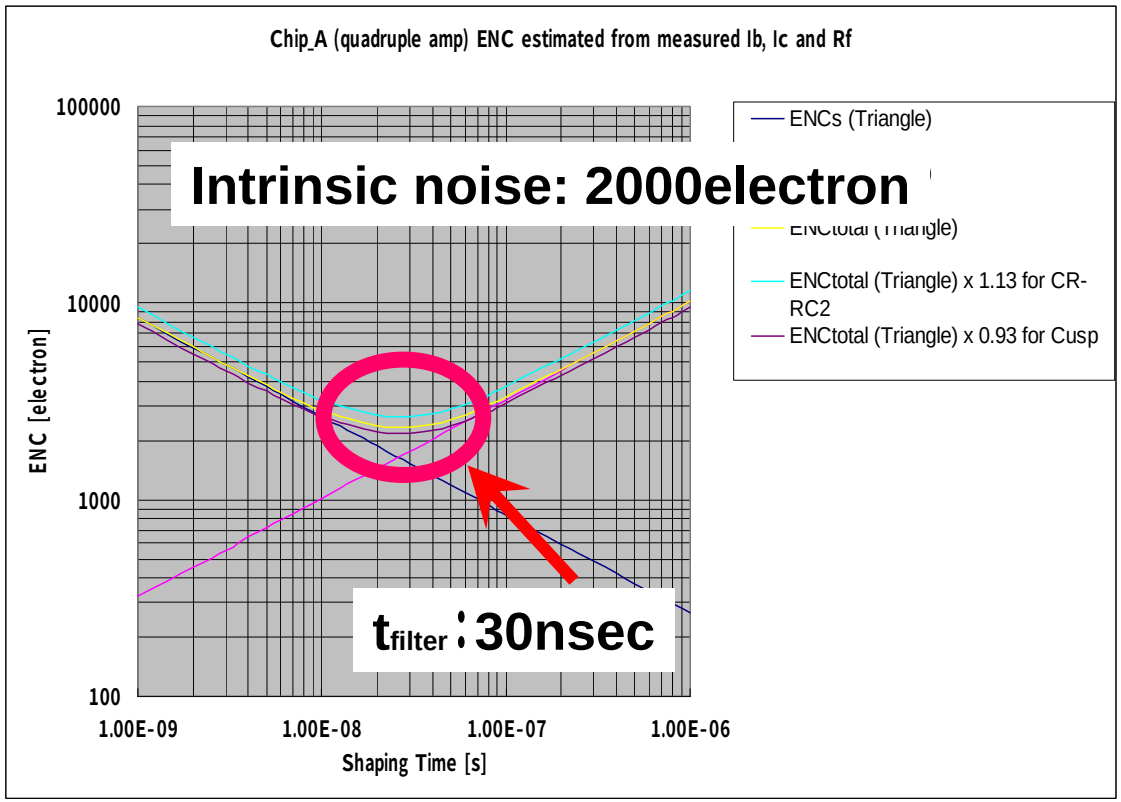
Detector
(13-inch HAPD)

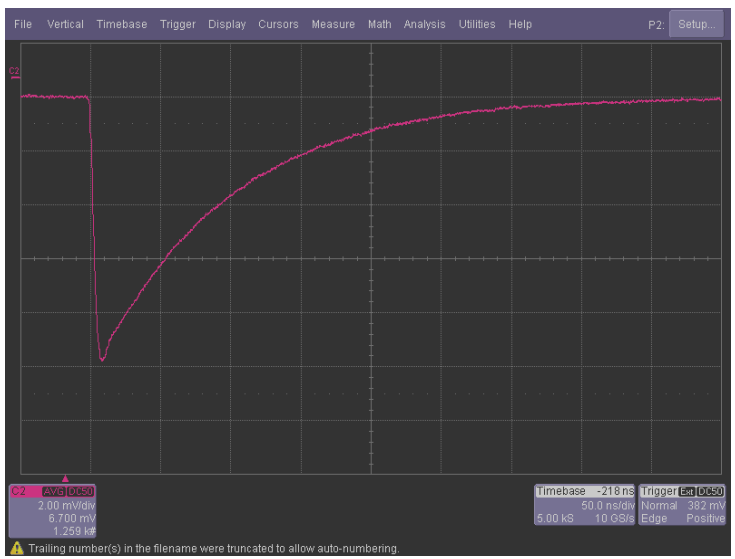
Pre-amplifier
(ASIC)

Analog memory cell &
Digital Filter (FPGA)

Front-end electronics

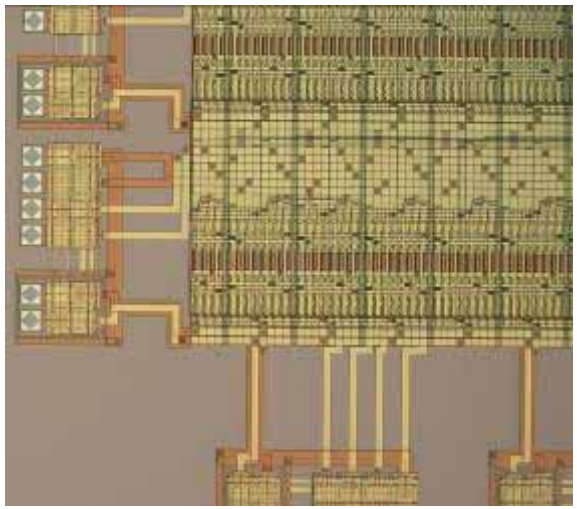


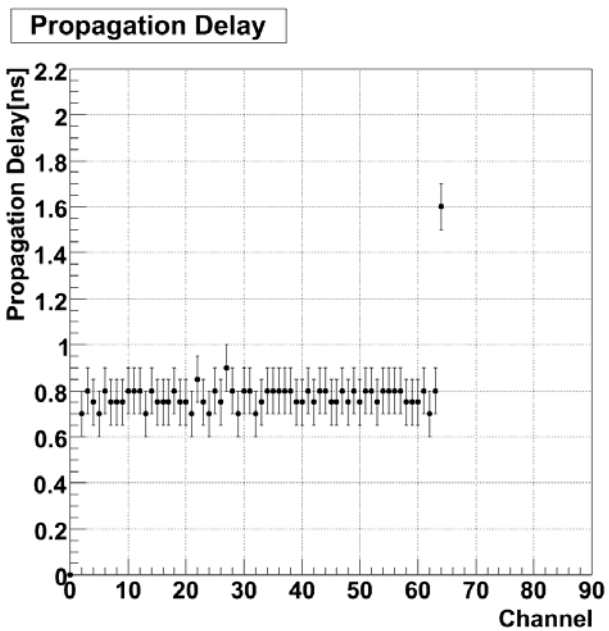




Rise time：＜1nsec
Dynamic range：2V
Power consumption : ~4mW/ch
(depends on driving capability)

Analog memory cell



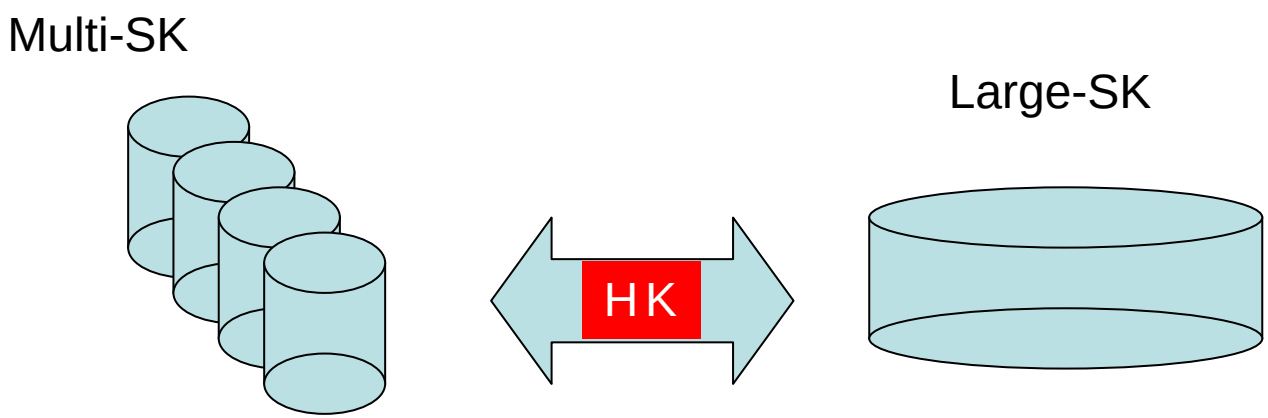


Performance (measured)

- Sampling period : 1Gsps
- Dynamic range : 3.5V
- Integral nonlinearity 0.1% for 2.5V
- Uniformity of sampling period <100ps
- 50mW/ch

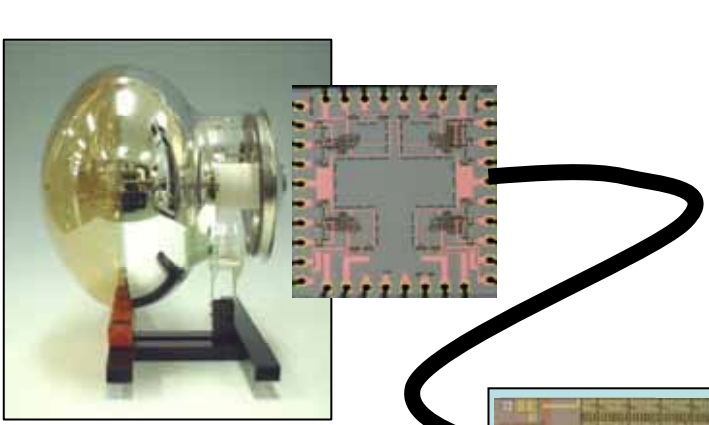
HPD system in the next step

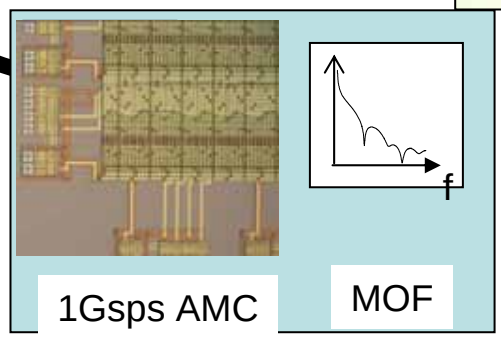
- In the next step (after several modifications)
  - Stability for temperature (for general purpose)
  - Evaluation of long term stability
  - Optimization of manufacturing process for production cost
    - Photocathode formation
    - Low cost material
    - Quality check during production ….
  - Customization of electronics/system for HK



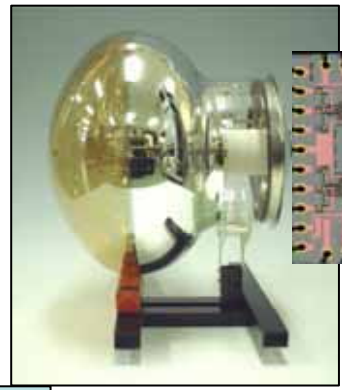
Two directions

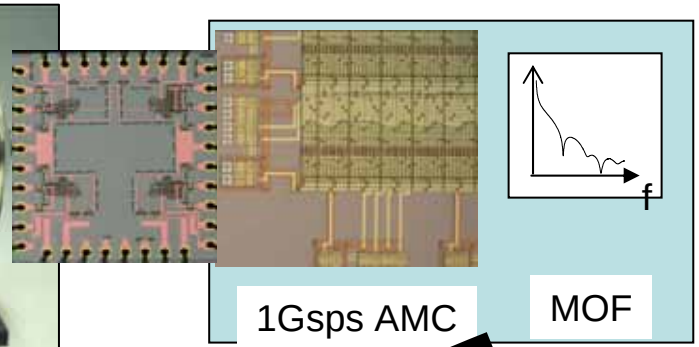
- **Similar to SK**
- **On HPD**





Ethernet





Digital data through Ethernet

Development of common devices

After determination of timing I/F(i.e. trigger, clock ..)
Multi-chip module or deep submicron ASIC (blue rectangle part) will be developed as a building block of the readout system.

Summary

We have developed a 13-inch HPD and confirmed

- ✓Excellent Single Photon Time Resolution of ~190 ps (σ)
- ✓Excellent Single Photon Energy Resolution of ~44 %
- ✓Total Gain of >2 x 10^5

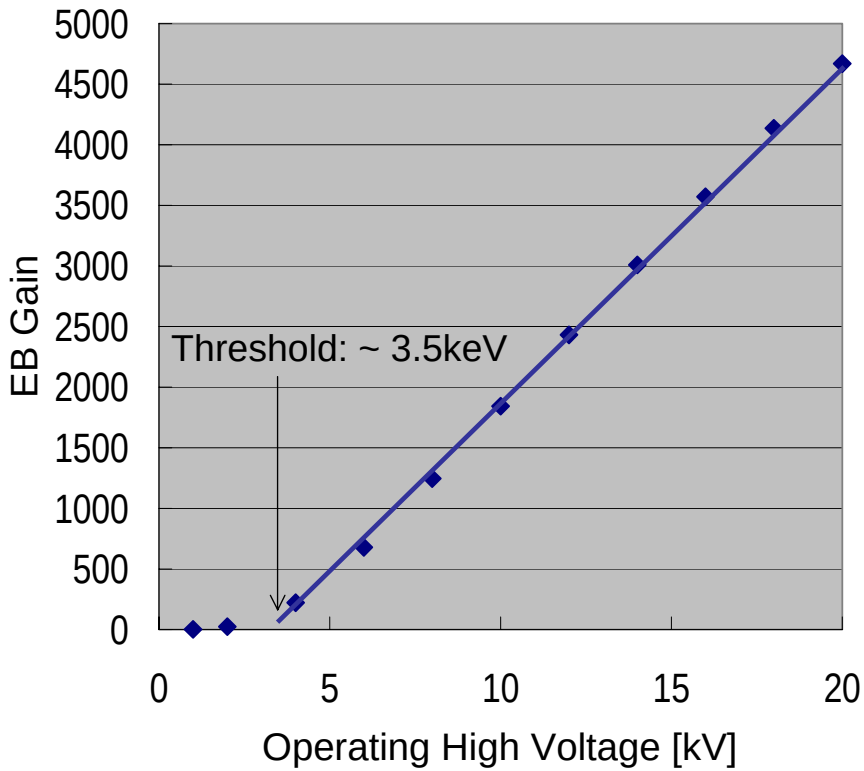
Promising as a photosensor for the next generation water-Cherenkov detector.

Next Steps

- ☐Optimization of manufacturing process
- ☐Evaluation of long-term operation stability
- ☐Readout electronics customization

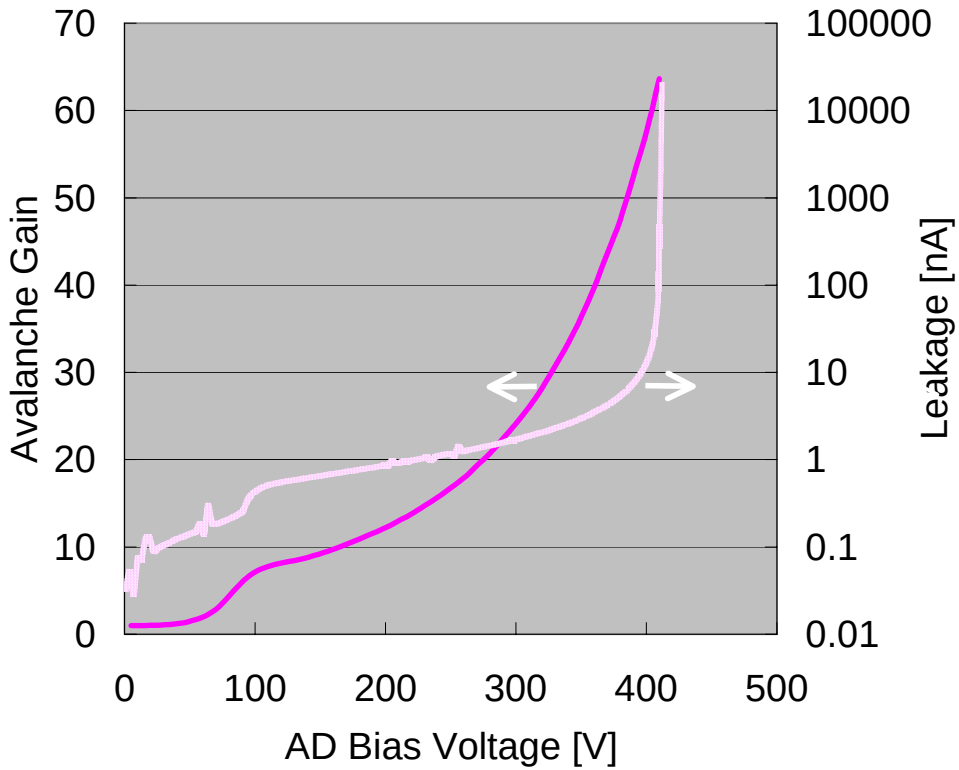
EB and Avalanche Gain

AD Bias=30V(fixed), HV=Swept



Gain=~4700 @20kV

HV=+10kV(fixed), Bias=Swept



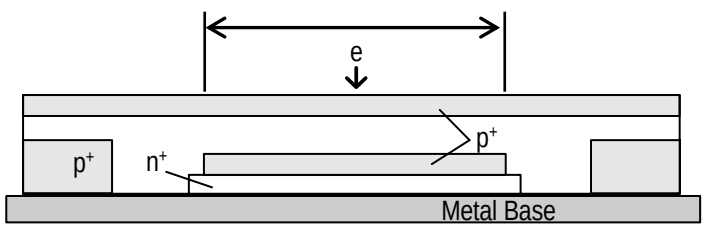
Gain=~50 @390kV

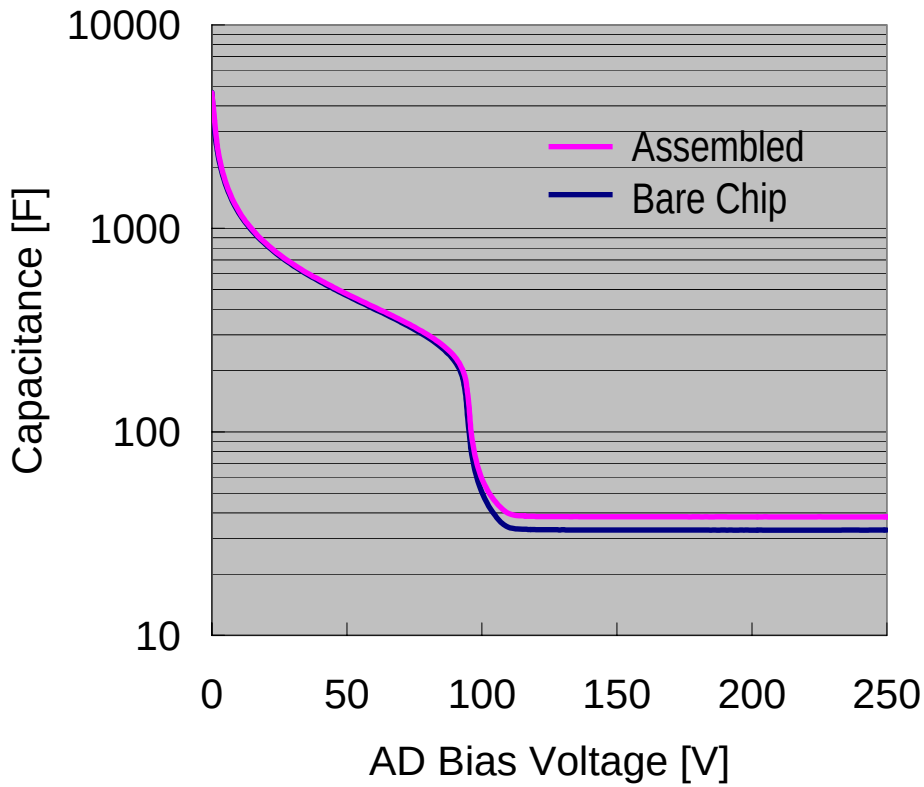
Incorporated Avalanche Diode and its C-V Characteristics

Capacitance: ~40pF over bias voltage of 120V (assembled on the base)

Backside Illumination Avalanche Diode

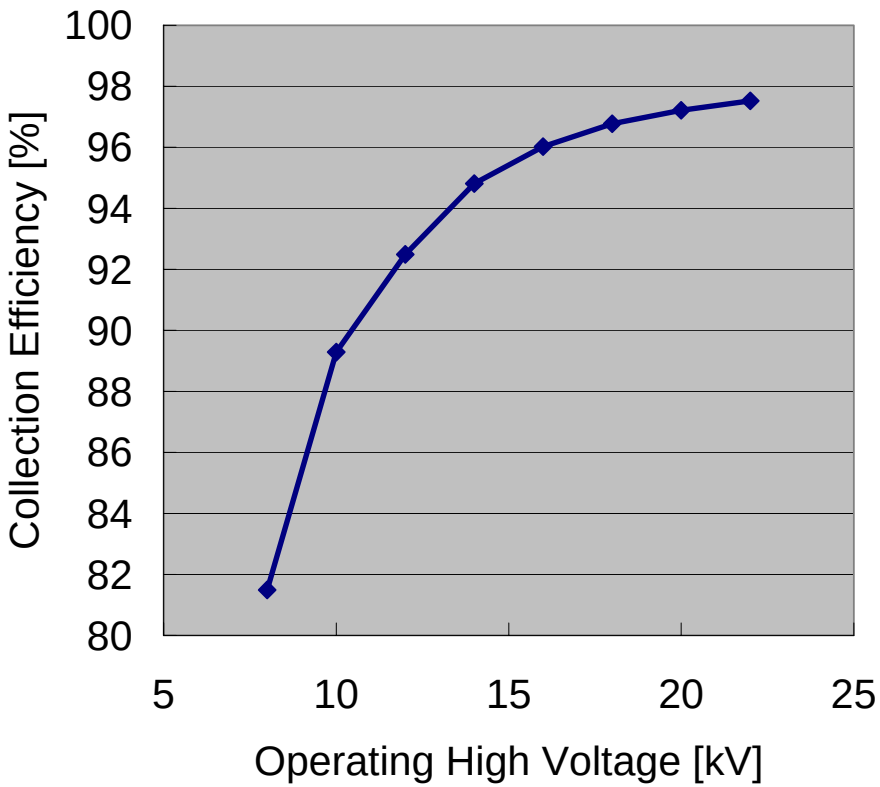
Effective Area: 5mm in dia.





Photoelectron Collection Efficiency and Effect of Magnetic Field (*Simulation*)

Photoelectron Collection Efficiency as a function of HV (No Magnetic Field)



Collection Efficiency as a function of Magnetic Field (at HV of +20kV)